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ABSTRACT

This paper examines human phonosensitivity (the process by which an organism receives acoustic stimuli and integrates them into its behavior patterns), which is divided into two distinct but inseparable systems: hearing, which controls the reception, transmission, and perception of acoustic stimuli, and listening, which controls the discrimination and identification of the stimuli as well as their integration in the organism's behavior patterns and memories. Any sound whose acoustic parameters meet the general criteria of simple audibility will generally activate hearing. The activation of listening, however, depends upon a series of conditions imposed by the specific nature of the message and the physiological state of the hearer. Five propositions are presented concerning the role of these conditions: (1) the process of hearing is globally different from listening, but integrating a sound stimulus can only result from activation of the entire chain of processes; (2) hearing is an essentially non-selective activity while listening is essentially selective; (3) hearing has no specialized function in relation to "affectivity," while listening does; (4) hearing is essentially automatic, while listening is in some measure voluntary; and (5) although hearing is obviously an absolute prerequisite for normal auditory-phonatory behavior, only the listening process ensures the adaptation of the audiophonological circuits necessary for emitting vocal messages in particular environments. (Includes 16 reference notes.) (JDD)

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HEARING, LISTENING AND PHONOSENSITIVITY

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(The present document is translated from the French, Italian and Dutch originals q. cit ...)

Anyone who is professionnally occupied with language or music understands intuitively that there is a fundamental difference between hearing and listening, a sentiment which is reinforced by the existence of separate words in most Indo-European languages to denote the two processes. Although peripheral and central hearing disorders have long been differentiated in neuropsychology, the distinction has often been limited to locating pathological processes (ear, auditory pathways, brainstem or cortex) than of recognizing two distinct but interrelated information-processing systems within the higher cognitive functions.

Recent advances in the treatment of central language processing disorders in the absence of specific auditory or phonatory tract pathologies suggest that, in fact, the difference between hearing and listening can be demonstrated on a neuropsychological basis. From this point of view, human phonosensitivity (the process by which the organism receives acoustic stimuli and integrates them into its behavior patterns) is divided into two distinct but inseparable systems: hearing, which controls the reception, transmission and perception of acoustic stimuli and listening, which controls the discrimination and identification of these same stimuli as well as their integration in the organisms behavior patterns and memories. The importance of this distinction for specialists in communication disorders is fundamental, if we are to understand patients who are incapable of comprehending or integrating acoustic messages despite physiologically normal peripheral auditory function and in the absence of auditory agnosia.

At its simplest, hearing might be defined as the transmission of envrionmental acoustic stimuli to the cortex through the ear and the auditory pathways, a process limited to the perception, peripheral analysis and transmission of all sounds capable of exciting the auditory apparatus. Of course, not all environmental sounds activate the auditory system, since it is generally only sensitive to stimuli falling within certain limits of frequency and intensity:

FIGURE 1

Even within these limits, the sensation produced by a sound which has effectively stimulated the auditory apparatus is yet more selective, since:

1. we do not react to all audible sounds in the environment,
2. we can make affective judgements about a given heard sound, and not about another equally well perceived; and,

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3. even if an acoustic message produces patent electro-physiological and neuromuscular reactions, these reactions are conditioned by the nature of the message received and the relative importance we attribute to it (1).

These aspects of auditory selectivity correspnd to six consecutive stages in the process of integrating acoustic messages:

HEARING	1. Reception	The sound is received by the peripheral mechanism (the ear)
	2. Transmission	The sound is transmitted along the auditory pathways to various sub-cortical relays and centers and to the thalamus
	3. Perception	The message is projected into the auditory cortex
LISTENING	4. Discrimination	The message is associated with earlier acoustic experiences in order to discover its nature and source
	5. Identification	The sense or meaning of the message is decoded
	6. Integration	The message is integrated into the immediate or characteristic behavior of the hearer if the message produces - a global reaction of the organism - a specific behavioral reaction - a form of behavior - a subsequent transitory behavioral modification - a subsequent permanent behavioral modification

Obviously, any sound whose acoustic parameters meet the general criteria of simple audibility will generally activate the first three of these stages in the physiologically normal peripheral auditory system. The activation of the remaining stages, however, depends upon a series of conditions imposed by the specific nature of the message and by the physiological state of the hearer.

Some of these conditions are still only partially understood but the general principles of their role in human phonosensitivity can be set forth in the following five propositions.

Proposition 1: Stages 1, 2 and 3 (hearing) described above constitute a process which is globally different from stages 4, 5 and 6 (listening), but integrating a sound stimulus can only result from the activation of the entire chain.

In the earliest studies concerning the hearing-listening difference using normal subjects (2), free of auditory, brainstem or cortical pathologies, the ear was bypassed by simple direct electrical stimulation of the auditory cortex. Relatively specific acoustic sensations were produced at each discharge of the implanted electrodes, demonstrating that cortical sound sensitivity is functional even in the absence of direct stimulation of the ear.

On the other hand, experiments with brain-damaged subjects with normal hearing (3) showed that stimulation of the ear only evoked vague sensations which the subject could not associate systematically with their real sources.

Although more precise and complex experiments with varied populations have subsequently been carried out (4), their results converge on at least one fundamental point: stimulation of the normal ear is ineffective unless it excites the central integrative regulatory systems capable of stocked mnemonic engrammes and of programming stable behavioral responses.

If we compare the precise but unpredictable sensations produced by direct cortical stimulation with the dissociated sensations evoked by auditory stimulation in the presence of auditory, brainstem or cortical pathologies, it seems evident that:

1. The two processes must be conjugated so that the sensation becomes both precise and identifiable and

2. the brainstem nuclei and the auditory cortex represent the essential relay between hearing and listening.

Proposition 2: Hearing is an essentially non-selective activity while listening is essentially selective. This selectivity is in direct relation to the quality of the hearer's attention and to certain specific characteristics of the acoustic stimulation itself.

The ear receives all the supraliminary acoustic stimuli in its environment, whether the organism is awake or asleep. The listening process, however, as we define it here, not only depends upon an awake organism but also upon certain specific qualities of vigilance on which the possibility of structured phasic reactions to the acoustic stimuli received depends. During sleep, with predominantly synchronic electrophysiological brain activity, the thresholds of excitability of the auditory cortex rise and only certain strong stimulations are capable of producing sufficient desynchronisation for the stimulus to be recognized.

When the organism is awake, the acoustic thresholds are lower. However, for a structured semantic message to be integrated into the mnemonic and sensory-motor circuits as we have described them, the simple state of wakefulness is insufficient. A particular state of attention is required and which can be measured by evoked auditory cognitive potentials.

Although basic vigilance levels are determined by endogeneous systems, the accrued level of attention we are concerned with depends largely on the activity of the ascendant reticular activating formation in the brainstem which receives afferences from all peripheral sensory systems (5). When effectively stimulated, it acts on the cortex by means of the posterior hypothalamus and certain thalamic nuclei. This action generates quantitive and qualitative changes in the electrophysiological activity of specific areas of the cortex. The absence of reticular stimulation is generally accompanied by faulty or incomplete understanding of the exterior sound stimulation.

However, the definitive attentional support of the listening process requires an even greater specificity which is conditioned by the specific type of acoustic information contained in the stimulus (6) . This particular activity is demonstrated by evoked auditory cognitive potentials, which, obtained in response to particular stimuli, constitue the proof of selective listening attention at that moment. Such "alerting" messages possess certain acoustic characteristics which current research has shown to be:

- novelty
- particular harmonic structure
- rhythmic complexity
- coding.

These characteristics can be defined according to the following principles.

All acoustic messages are composed of four physical manifestations: frequency, intensity, timbre and length. The arbitrary synchronic and diachronic organization of these parameters constitute the typical acoustic message between intelligent entities in a communicative situation.

Acoustic messages can be classified in five groups:

1. Simple synchronic: "pure-tone" signals in which two parameters (frequency and intensity) occur together in a given time-span, which is the third parameter. This type of message is perceived as a vibratory phenomenon whose origin is unidentifiable because of the absence of timbre. Under this type of stimulation, the hearer's E.E.G. is only minimally modified, and then only in the auditory cortex. Furthermore, only the onset of the stimulation is effective, since even these small electrophysiological alterations are rapidly extinguished. Most subjects are incapable of imitating the stimulus correctly after a three-second delay.

2. Simple periodic: messages of Type 1 above, repeated a certain number of times in a given period. These messages may be rhythmic (whith predicatable intervals) or arrhythmic (with unpredictable intervals)

FIGURE 2

Here again, the absence of timbre makes it impossible to identify the source. The E.E.G. data are similar to those obtained by Type 1 messages and the repetition of these signals does not significantly mitigate the onset of fatigue (7) .

3. Complex synchronic: for example, a chord, composed of two or more simultaneous Type 1 messages. Here the multiple series of harmonics introduces the factor of timbre and experimental subjects respond by both auditory and associative desynchronizations. Some spontaneous motor activity is often present. Although memory extinction is as rapid as before, the reactions obtained represent the border between hearing and listening, since some associative areas are activated. This is due to the presence of timbre, which permits at least a partial identification of the likely source of the signal.

4. Complex periodic: like type 3, but repeated rhythmically or arrhythmically. Here again, some associative cortex activity is manifest. Motor activity is now present in a majority of subjects (and is often stable, such as foot- or hand-tapping). Thus, the addition of a rhythmic component in a harmonically-complex message intensifies the listening process.

FIGURE 3

5. Discursive: a sequence of Type 3 and 4 messages, arbitrarily organized and associated with a code, generally of the learned type. This type of message meets the criteria we have established for supraliminary listening stimuli: harmonic complexity created by the structure of the phonatory tractus with its multiple resonance chambers, rhythmic complexity and "novelty", since the exact contents of this type of message cannot generally be accurately predicted by the hearer until fully emitted.

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Although our example here is language, it is important to note that any discursive acoustic message which meets the criteria mentioned is capable of triggering the listening process.

In addition to the associative and simple motor activities described above, this type of message activates:

- the cortical relays between the auditory cortex and the frontal and parietal associative zones
- the cortical relays between these associative areas and the pre-motor area, and
- the access to the longer-term memories.

This system permits a greater precision in the adaptation of the motor responses and a much slower memory extinction (which results in a better engramme of the expérience). Electro-physiological exploration of cortical activity and the study of the effects of cortical lesions allow us to trace the sequence of events in this chain, which we can illustrate very schematically in the following diagram. Here the auditory stimulation is linguistic and generates a phonatory response:

FIGURE 4

The message is received in the auditory cortex (1) which is the principal cortical relay in the hearing-listening process, and is transmitted to the parietal gyrus angularis (2) where all other simultaneously received sensory information is associated with the auditory message. A certain hierarchical filtering occurs here by which one or another of these information types is given priority and is selectively forwarded to specific cortical areas. In the case of the priority of the linguistic message (our example here), it is channeled to the pre-frontal cortex (Broca's area, in this case), which is responsible for discriminating the message in such a way that it is subsequently transmitted to the appropriate frontal associative (4) and mnemonic areas, as well as to the corresponding longer-term memory zones (5, 6). Once associated with the corresponding codes and past experiences (8) , the message returns to the second relay (7) and can provoke an adapted exteriorized reaction after transmission to the pre-motor and motor cortex (8, 9).

Proposition 3: Hearing has no specialized function in relation to "affectivity", while listening does. To a large extent, the attitude of the speaker toward his own message is contained in its non-segmental (i.e., prosodic) structure (9) .

The auditory perception of prosodic features is based on structured variations of frequency, intensity, timbre, length and rhythm and is essentially the same in either ear. However, discriminating, identifying and integrating these variations is a matter of the listening process, which not only treats this information in a special way, but does so differently in each hemisphere.

After primary projection of the prosodic information onto the opposite cortical hemisphere (10), the binaurally-perceived prosodic information is discriminated, identified and integrated preferentially by the right hémisphere, while the "digital" or "linear" components (the segmental vowel-consonant sequences) are discriminated, identified and integrated preferentially by the left hemisphere (11). This right hemisphere specificity has been demonstrated by experiments with non hearing-impaired brain-damaged adults (12). When confronted with verbal stimuli with varying intonation curves, the subjects were asked to associate them with various enlarged photographs of facial attitudes. The phrases used contained no structural clues as to their likely intonation (in English, for example, no do-questions, etc.). The global and right-damaged subjects were unable to respond correctly, while the left-damaged subjects had fewer problems with the correct answers.

Of course, for a sound message to be fully understood, both the "digital-linear" and "anological-parallel" information must eventually be integrated through the coordination of both hemispheres. Brown and colls. (13) have demonstrated that this final comprehension stage is bi-hemispheric. Here, the encephalographic data were recorded while subjects attempted to differenciate the meaning of verb-noun homophones such as "rows" and "rose".

FIGURE 5

According to whether the sound stimulus is musical, linguistic or of other types, and according to certain characteristics of the listener (sex, handedness, etc.) (14), the exact intra-hemispheric position of the maximal and minimal responses may change, but the initial hemispheric specificity and subsequent bi-hemispheric integration are confirmed.

Thus, while the hearing process is essentially bilateral, the listening process is hemispherically specialized.

The brain-damage experiments described above demonstrate that the sensori-motor integration of either the denotative or connotative contents of spoken messages is severaly impeded according to which hemisphere is damaged. Analogous difficulties obviously occur with regard to musical and other types of acoustic messages. Thus, normal binaural hearing cannot guarantee normal listening, whose highest function depends upon hemispheric specialization and subsequent bi-hemispheric integration.

Proposition 4: Hearing is essentially automatic, while listening is in some measure voluntary. "Voluntary" sensory activity can be related to the psychological state of the listener. One cannot totally block the acuity of the ear, but can, in fact diminish it when certain messages are perceived, as in the case of "Anne" (15). This young woman of 19 became suddenly selectively "deaf", apparently in a pathological family context.

Subjected to a myographic examination in which certain muscular reflexes to successive sound stimulations were measured, Anne did in fact react involuntarily to the first auditory stimulation. Surprisingly, the second stimulation identical to the first, one minute later produced no measurable muscular reflex. Apparently, when Anne detected certain voices or certain messages (listening) she was able to reduce sufficiently the tension of the middle-ear muscles (hearing) to impede further cochlear excitation.

Thus, Anne was able to create an integrative blockage in the interval between the two stimulations. Her hearing mechanism was obviously functional during the two tests, but the listening process was capable of a rapid and efficient retroaction on the hearing mechanism in the second.

Proposition 5: Although hearing is obviously an absolute pre-requisite for normal auditory-phonatory behavior, only the listening process insures the adaptation of the audio-phonological circuits necessary for emitting vocal messages in particular environments. These circuits depend upon our own phonatory behavior as well as on that of other speakers around us. The phonatory motor act is thus controlled by the sounds produced and heard through air and bone conduction by the speaker himself, and constitutes a retroactive sensori-motor circuit.

Myographic studies of the phonatory muscles of subjects under acoustic stimulation show that discursive stimuli almost always produce a pre-phonatory response. By "pre-phonatory", we refer to changes in the pulmonary, tracheal, laryngeal, lingual anf facial muscles, similar to the changes which precede the emission of speech or singing resulting from the subcortical reflex circuits. The hearing process is sufficient to trigger these reflexes. However, the exact muscular tone varies considerably as the speaker begins to hear his own voice through the retroactiove circuit. Thus, once again, it is the listening process which produces a fully-adapted phonatory emission.

At the hearing level, the pre-phonatory response is conditioned by three middle-ear strucutres: the tympanic tensor muscle, the stapedian muscle and the Eustachian tube. The muscles alter the tension of the eardrum and of the oval window to protect these two membranes from damage by excessively loud noises. Their action is however not entirely reflex, since both are innervated by cranial nerve pairs (the tympanic tensor by the trigeminal and the stapedian by the facial nerve).

These same pairs selectively innervate the velum, the chewing and swallowing muscles as well as the surface muscles of the face, all of which intervene directly in phonatory activity. The Eustachian tube, in turn, transmits the vibratory energy to and from the middle ear and the oral and pharyngeal cavities where they ara perceived by the sensory fibres of the trigemenal, thus completing the circuit. Other mechanisms can likewise intervene in this process, such as the cochlear-recurrent circuit which, after cochlear stimulation, adapts laryngeal muscle tone to pre-phonatory posture.

If all these means of obtaining a pre-phonaory laryngeal posture can be activated by the hearing process alone, experimental evidence shows that phonatory behavior integrating both phonemic and prosodic features can only be obtained through the listening process. In these experiments, filtered linguistic and musical stimuli were injected alternatively in the left and right ears, of left and right brain-damaged subjects. These subjects were asked to vocalize during the experiment, trying to imitate the stimuli as closely as possible. All subjects manifested relatively satisfactory pre-phonatory muscle tone, since all posessed normal hearing and were capable of producing noises. Although the right-damaged subjects repeated the stimuli more accurately at the segmental phonemic level when receiving a linguistic stimulus, their vocalizations often resembled a recitativo or Sprechstimme, regardless of the kind of stimulus. The left-damaged subjects vocalized better under musical stimulation but their phonatory productions were often inaccurate and had a characteristically singing quality regardless of the kind of stimulation (16).

With these five propositions we have attempted to demonstrate that hearing and listening are not synonyms for a simple process of sound integration in the human being. Rather, human phonosensitivity is composed of at least two systems, hearing and listening, each being specifically defined. Normal hearing does not automatically assume normal listening and only normal listening permits fully structured and adapted phonatory behavior. If these reflections are of some interest to professionals in linguistics, elocution, singing and foreign language teaching, they are in our opinion essential for professionals in the fields of central auditory processing disorders, speech and hearing therapy and neuropsychology.

NOTES

1. Feldman D., Gardey P. and Raynaud J. INTRODUCTION A L'ACOUSTICO-THERAPIE. Pau: A.F.A.P.P., 1985

2. The pioneering studies were reported in Penfield R. and Roberts L. SPEECH AND BRAIN MECHANISMS. Princeton: Princeton University Press, 1959.

3. Goodhill V. Pathology, diagnosis and therapy of deafness. In Travis L. HANDBOOK OF SPEECH PATHOLOGY. New York: Appleton, 1957, 313 ff.

4. This research is summarized by Liepp E. LA MACHINE A ECOUTER. Paris: Masson, 1977.

5. Picat J. PSYCHO-PHYSIOLOGIE DU SYSTEME NERVEUX CENTRAL. Paris: Ellipses, 1980.

6. Ibid.

7. Cavaggioni A et al. Réaction d'habituation. In LA VIGILANCE. Paris: Clin-Colmar, 1972, 44-46.

8. The association of a sound message with learned codes involves at least three memory areas: the prefrontal cortex, the amygdalian complex and the hippocampus. The latter is in intimate relation with the septum through which messages from the hypothalamus and the associative cortex pass. Thus, the hippocampus intervenes directly in the association of fresh sensory information with past experience. Karli P. Neurophysiologie du comportement. In Kayser C., ed., PHYSIOLOGIE. Paris: Flammarion. 1976, Vol. 2, 1331-1354.

9. And also, of course, in the quality of the voice itself, although this point cannot be explored in the limits of the present essay. See Feldman D. Stimulation auditive par sons filtrés dans la rééducation des dysphonies. REVUE DE PHONETIQUE APPLIQUEE 71-72 (1984) 243-251.

10. There are, however, homolateral fibres (around 12%). See Feldman D., Gardey P. and Raynaud J. op. cit. ch. 3.

11. See the articles by Barrosso, Kinsbourne and Neville in Reiber R., ed. THE NEUROPHYSIOLOGY OF LANGUAGE. London: Plenum, 1976.

12. These experiments are described by Weniger D. Influence of prosodic features in language comprehension of aphasic patients. In Creutzfeldt O. et al. HEARING MECHANISMS AND SPEECH. Berlin: Spinger 1979, 406-413. The others are reported by Blumstein S. and Cooper W. Hemispheric processing of intonation contours. CORTEX 10 (1974) 146-158, and by Zurif E. Auditory lateralization. BRAIN AND LANGUAGE 1 (1974) 391-404.

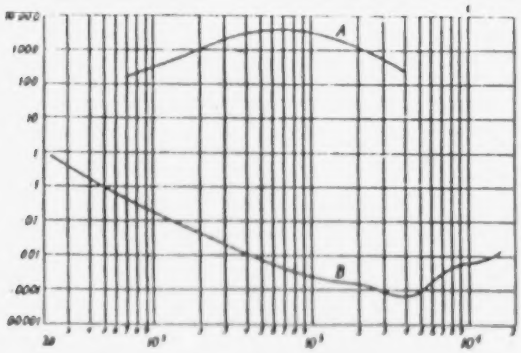
13. Reported in Brown W. et al. Verb and noun meaning of homophone words. In Creutzfeld O., ed. op. cit., 159-168.

14. See McGlone J. Sex differences in human brain assymetry. BEHAVIORAL AND BRAIN SCIENCE 3 (1980) 215-263., and Brown W. et al. Language lateralization, sex and stuttering. pre-publication ms., U.C.L.A.

15. Malmo R. Emotions and muscle tension. PSYCHOLOGY TODAY 3 (1970).

16. Feldman D., Gardey P. and Raynaud J. op. cit.

FIGURE 1



Auditory Thresholds

A. Auditory sensation threshold (Fletcher)

B. Audibility threshold (Wegel)

FIGURE 2

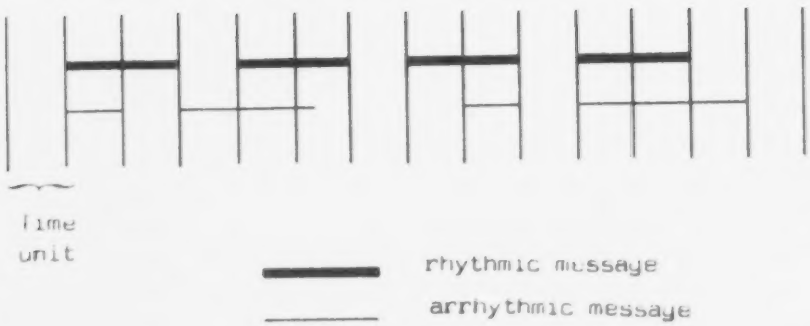


FIGURE 3

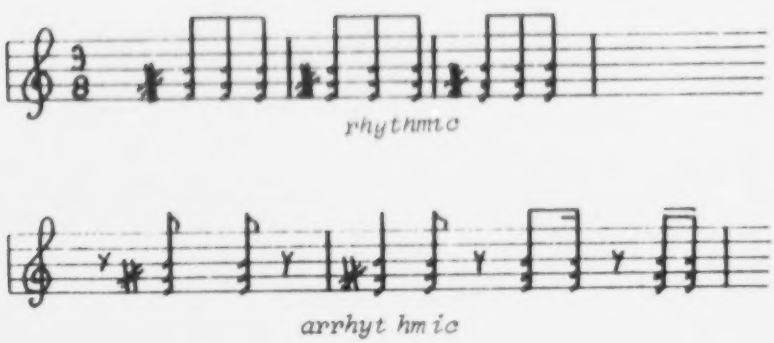



FIGURE 4

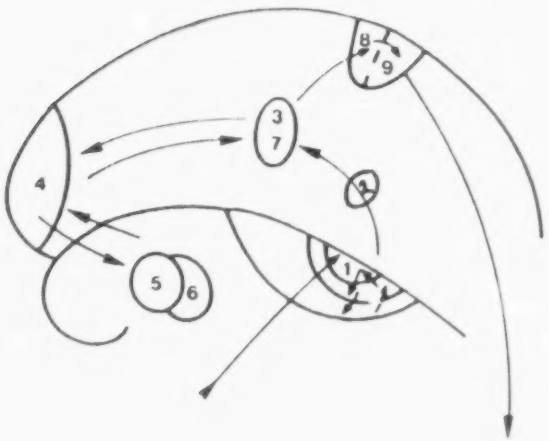
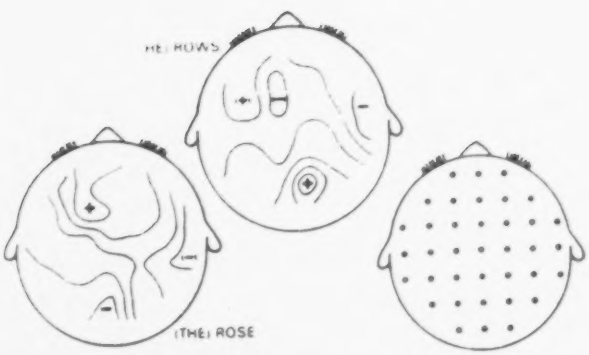


FIGURE 5



Evoked, average scalp field distributions on the scalp, 72 msec after onset of "rose" and "rows", recorded simultaneously from 37 channels (electrode positions see schema). Equipotential field lines are computer-interpolated in 0.25 uV steps. Maximal values +, minimal values -, lesser extreme values (+) and (-); head seen from above, nose up. (from Brown and Lehmann, in preparation)